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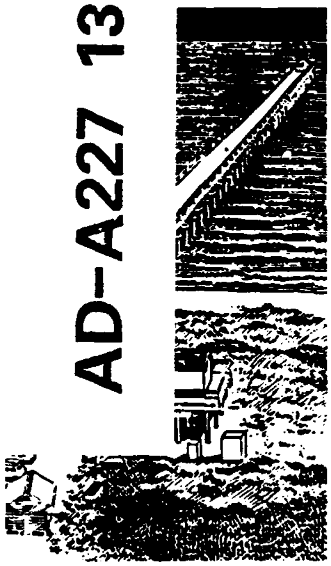

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AN ALTERNATIVE DESIGN APPROACH FOR DETACHED BREAKWATER PROJECTS

by

Julie Dean Rosati, Clifford L. Truitt

Coastal Engineering Research Center

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199

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An empirical method for design of detached breakwater projects is discussed, and several example problems are presented. The method was developed by the Japanese Ministry of Construction (JMC) based on a survey of over 1,500 projects constructed from 1983 through 1985. Design of detached breakwater systems using the JMC method tends to result in more numerous, shorter length segments positioned closer to the shore than observed in US projects. However, the JMC method may complement other design methods, perhaps also providing suggestions for future research and monitoring of existing projects.

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Preface

The study summarized in this report was authorized by Headquarters, US Army Corps of Engineers (HQUSACE), and was performed as a part of the Civil Works Research and Development Work Unit 32535, "Engineering Performance of Coastal Structures." Mr. John H. Lockhart, Jr., was HQUSACE Technical Monitor. Funds were provided through the Coastal Structures and Evaluation Branch (CSEB), Engineering Development Division (EDD), Coastal Engineering Research Center (CERC), of the US Army Engineer Waterways Experiment Station (WES), Vicksburg, MS.

Work was performed under the general supervision of Dr. Yen-hsi Chu, Chief, Engineering Applications Unit (EAU), CSEB; Ms. Joan Pope, Chief, CSEB; Mr. Thomas W. Richardson, Chief, EDD; Dr. C. Linwood Vincent, Program Manager, CERC; Mr. Charles C. Calhoun, Jr., Assistant Chief, CERC; and Dr. James R. Houston, Chief, CERC.

This report was prepared by the Principal Investigator (PI) of the work unit, Ms. Julie Dean Rosati, Hydraulic Engineer, EAU, CSEB, and former PI of the work unit, Dr. Clifford L. Truitt, EAU, CSEB.

COL Larry B. Fulton, EN, was Commander and Director of WES during the publication of this report. Dr. Robert W. Whalin was Technical Director.

Contents

AN ALTERNATIVE DESIGN APPROACH FOR DETACHED BREAKWATER PROJECTS

Introduction

1. The evolution of any engineered design or design process invariably must include feedback about the performance of prototype structures. As detached breakwater projects are constructed and monitored, understanding of the associated shoreline response will improve, and the design approach for such structures will become more refined. However, the number of US projects that have actually been constructed and evaluated to date is relatively small (Shore Protection Manual (SPM) 1984, US Army Corps of Engineers (USACE) 1984, Dally and Pope 1986, Pope and Dean 1986, Suh and Dalrymple 1987). As a result, there is very little specific engineering design guidance presently available in the US literature for planning such projects.

2. Only 17 detached breakwater projects (46 breakwater segments), built by the Corps either as erosion control structures or as sand traps to reduce the rate of deposition in navigable channels, exist along the 9,200 km of US shoreline. Seventy-one additional Corps segments are either in the early stages of construction or are planned for construction within the next few years.* Comparatively, at least 4,000 detached breakwater segments exist along Japan's 9,400-km coast (Seiji, Uda, and Tanaka 1987; Japanese Ministry of Construction (JMC) 1986).

3. An opportunity to accelerate the evolution of a design procedure that broadly considers prototype performance is potentially available in the Japanese experiences with breakwaters for shore protection. The River Bureau of the Japanese Ministry of Construction has published a handbook for the design of offshore breakwaters (JMC 1986) based on a survey of 1,552 projects constructed under the jurisdiction of the Ministry from 1983 through 1985. Results from this survey have also been discussed by Seiji, Uda, and Tanaka (1987) and Uda (1989). The performance results are combined with the results

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* Personal Communication, 1989, Edward Fulford, Chief, Coastal Planning Section, US Army Engineer District (USAED), Baltimore, Baltimore, MD, and Thomas Bender, Chief, Coastal Engineering Section, USAED, Buffalo, Buffalo, NY.

of a series of numerical model calculations and other information to produce a detailed step-by-step approach to structure design.

4. This report summarizes and presents the approach used in the JMC handbook and discusses results of its application to example problems. The intent of this report, however, is not to endorse (or reject) the JMC approach for unqualified use on Corps projects. Important differences exist between US and Japanese project purposes and justification. Both factors preclude endorsement of the approach described without additional study and evaluation. The methodology which will be described does, however, represent a rational approach to design that can be used as an alternative to the existing more qualitative and iterative approaches presently used in the United States.

JMC Breakwater Design Method

Introduction

5. The effect of detached breakwaters on a project beach can take one of three forms: (a) no significant effect of the structure on nearshore coastal processes and, therefore, no shoreline response; (b) moderate effect of the structure, resulting in seaward advancement of the beach planform, but not touching the structure; and (c) large influence of the structure on coastal processes, extending the beach planform completely to the structure. The general term "salient" describes both the unconnected and connected shoreline protrusions; the term "tombolo" describes the specific case in which a well-developed salient connects with the structure. Depending on the site, an unconnected salient or tombolo response is usually desired, although care must be taken to evaluate the effect on downdrift shorelines.

6. The structures surveyed by JMC included permeable, impermeable, continuous (length greater than 200 m), and segmented systems. However, the majority (1,458 or 94 percent) of the structures surveyed and the type of structure concluded to perform best at the sites of interest to the Ministry was a permeable segmented structure, constructed of armor units.

7. The JMC discusses a primary mode of sediment deposition observed in the lee of breakwaters at their sites: the onshore movement of material by sediment-laden waves breaking through a transmissible structure. The cross-shore accretion of material occurs in addition to longshore current deposition. Most of the structures surveyed by JMC are positioned inside the surf zone, where the structure functions to dissipate wave energy, thereby allowing suspended sediment moving onshore to deposit.

8. Tombolo formation occurred in about 60 percent of the cases reported in the JMC experience, with most shorelines advancing from 10 to 20 m. Ninety-eight percent of the structures studied were permeable. Contrary to US design practice, the use of beach fill placed to the lee of the structure(s) to ' itigate potential adverse effects of the project is not a part of the JMC design.

Procedure

9. The JMC presents a series of steps through which detached breakwaters can be designed. The JMC breakwater data were collected from five

types of coasts, distinguished by the beach profile, sediment size, relative intensity of sediment transport, and availability of a sediment source (Table 1). Enough data were available from two of these types of coasts (Beach Types B and C) to develop relationships between shoreline response and structural parameters. The wave parameters required for the JMC design are average height and period from the five highest nonstorm waves occurring in a year. Extracting the largest "storm" and "nonstorm" waves from readily available wave data (such as Wave Information Study) may be difficult, requiring judgment on the part of the designer. The effect of water-level changes on project design is not explicitly incorporated in the JMC procedure, although the effect of a given tide range, storm surge, setup, or lake level change can be evaluated by varying the structure's design depth. The term "salient" used in descriptions of the JMC method presented herein describes both connected (tombolo) and unconnected types of shoreline response. The JMC design method follows a series of steps as illustrated in Figure 1. Variables used in the design procedure are illustrated in Figure 2. Descriptions of each step are as follows:

a. Determine which beach type best describes project site based on beach profile shape and slope (I), availability and type of sediment, and coastal processes (Table 1).

b. Determine input parameters.

   (1) Waves. The deepwater wave height H_{o5} is calculated by averaging the five largest (nonstorm) deepwater waves occurring in a year; T_5 is the wave period corresponding to this deepwater wave height.

   (2) Desired protection. Determine length of shoreline to be protected (L_p).

c. Choose desired amount of shoreline advancement, the salient length (X_s).

d. Calculate breaking water depth at the site (d_{b5}) using deepwater wave steepness H_{o5}/L_{o5} where deepwater wavelength $L_{o5} = gT_5^2/2\pi$, and g is acceleration of gravity (Figure 3).

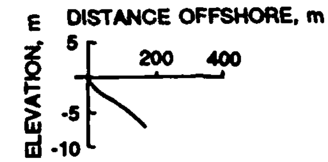
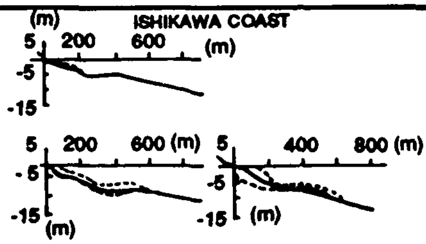
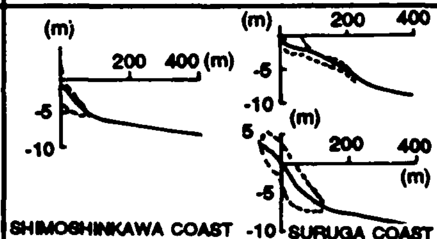
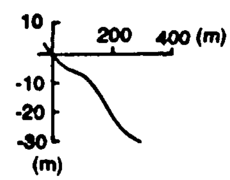
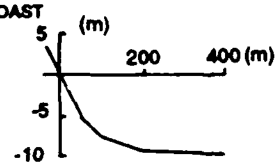
e. Choose an approximation to the design water depth at the structure, d', such that

$$d_{b5} > d' > X_s I \tag{1}$$

Table 1

Definition of Beach Type for Use in JMC Design Method

(Modified from JMC 1986)

TYPE OF BEACH	PROFILE	CHARACTERISTICS
A	AOMORI COAST 	• WATER DEPTH IS SHALLOW AT THE HORIZONTAL PORTION OF THE BOTTOM. • WAVE HEIGHT IS SMALL, AND DEPTH OF THRESHOLD FOR SEDIMENT MOVEMENT SMALL. $H_{05} < 0.5$ m, I = 1/30, FINE SAND
B	ISHIKAWA COAST 	• BAR IS WELL DEVELOPED. • BEACH SLOPE IS GENTLE AT DEPTH FOR THRESHOLD OF SEDIMENT MOTION. • COASTLINE IS PERPENDICULAR TO AVERAGE WAVE DIRECTION. $H_{05} \geq 0.5$ m, I = 1/30, SAND
C	SHIMOSHINKAWA COAST, SURUGA COAST 	• BOTTOM SLOPE IS RELATIVELY STEEP AND THERE IS NO BAR. $H_{05} \geq 0.5$ m, I = 1/15, SAND AND PEBBLES
D	FUJI COAST 	• BOTTOM SLOPE IS STEEP. $H_{05} \geq 0.5$ m, I = 1/3 TO 1/10, PEBBLES
E	KOOCHI COAST 	• SIMILAR TO TYPE-C, BUT IN SOME CASES THERE IS A BAR OFFSHORE. $H_{05} \geq 0.5$ m, I = 1/15, PEBBLES

LEGEND

——— AVERAGE BEACH PROFILE

- - - - - - AVERAGE DEVIATION

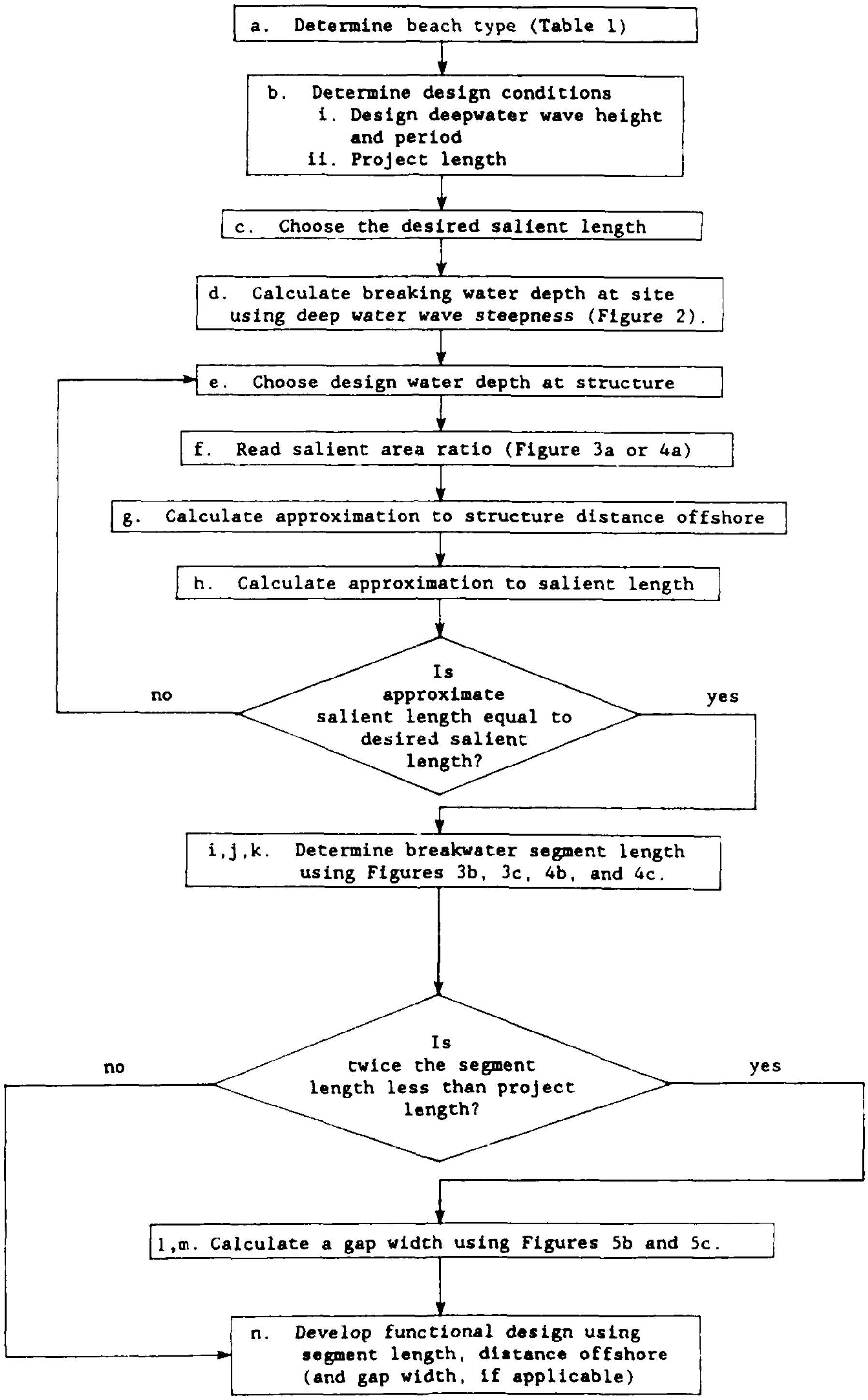
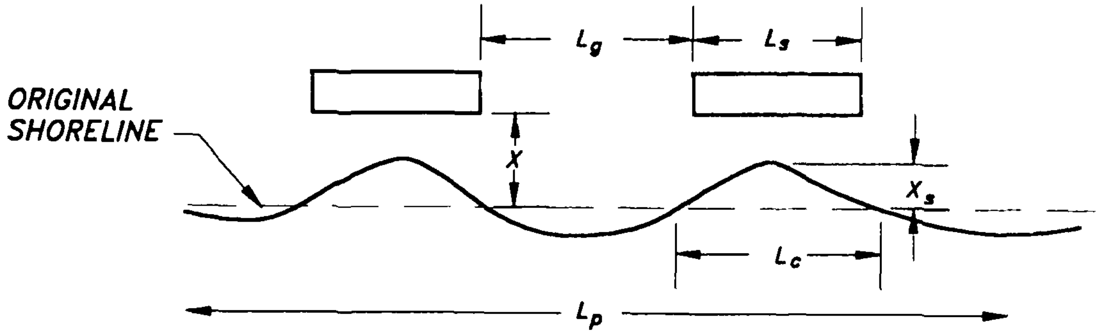
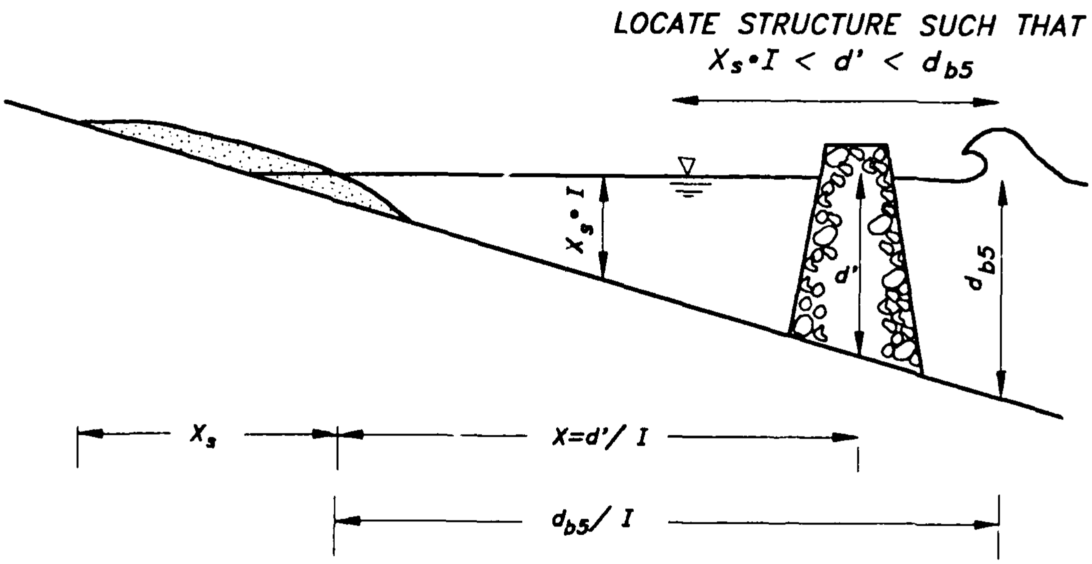


Figure 1. JMC design method



a. Plan view



b. Cross-sectional view

Figure 2. Variables used in JMC design method

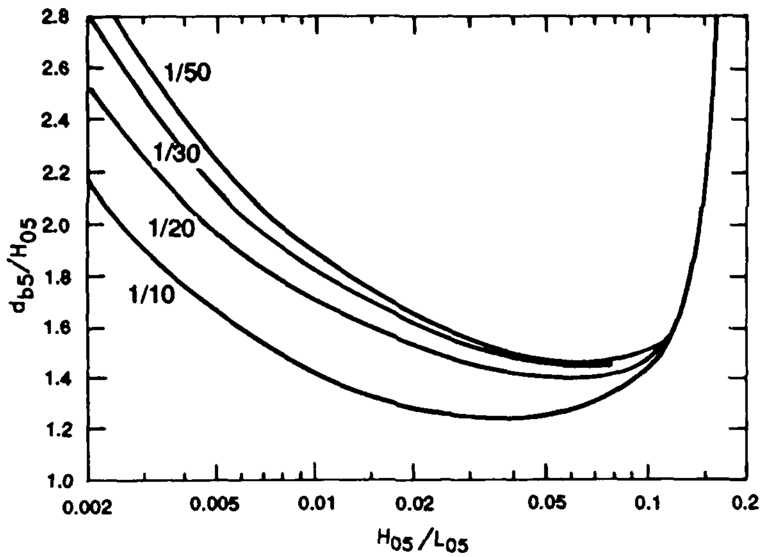


Figure 3. Deepwater wave steepness versus nearshore steepness for various beach slopes (Goda 1970)

Equation 1 will result in the structure being located at least one salient length offshore from the original shoreline, but shoreward of the breaker zone. A good initial guess is $d' = (d_{b5} + X_s I)/2$.

f. Read salient area ratio (SAR) from Figure 4 or 5 (Beach Type B or C) using the ratio of d'/d_{b5} . The *SAR* approximates the planform area of the salient as a triangle, and divides by the protected area as follows:

$$SAR = \frac{\frac{1}{2} L_c X_s}{X L_s} \tag{2}$$

where

L_c = salient length in longshore direction, measured at original shoreline position
X = segment distance offshore
L_s = segment length

g. Calculate first approximation to structure distance offshore, X' :

$$X' = \frac{d'}{I} \tag{3}$$

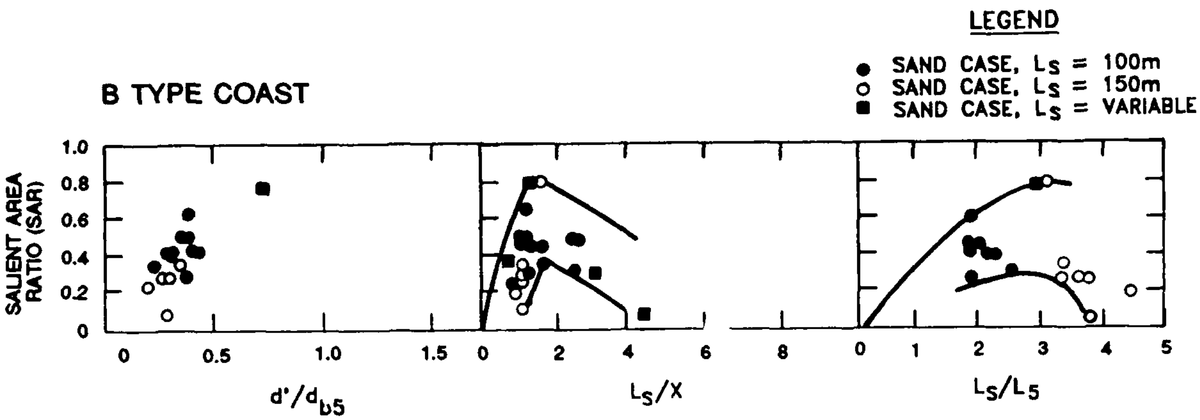


Figure 4. Salient area ratio versus site parameters for Beach Type B (modified from JMC 1986)

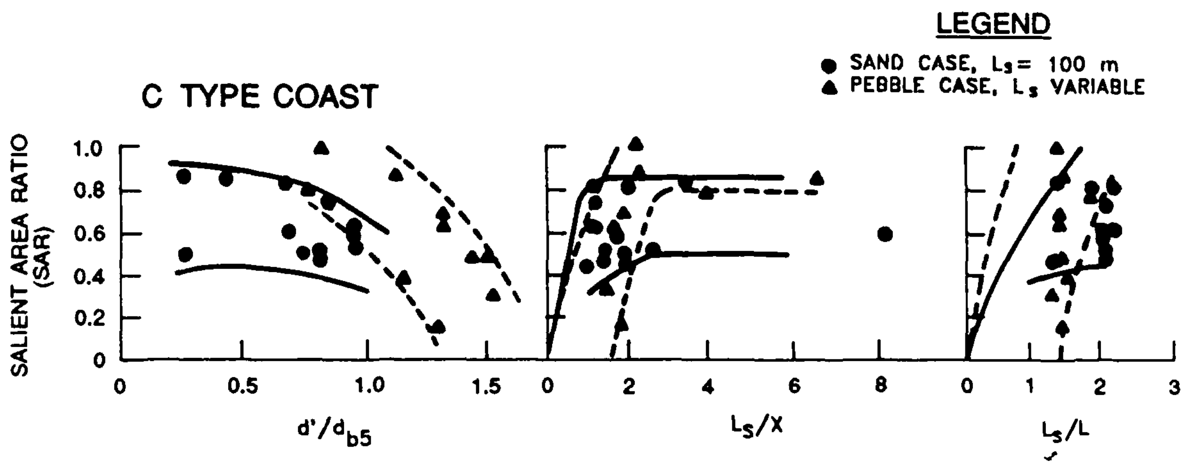


Figure 5. Salient area ratio versus site parameters for Beach Type C (modified from JMC 1986)

h. Calculate X_s' , a first approximation of the salient extension formed, as follows:

$$X_s' = SAR\ X' \tag{4}$$

If X_s' is approximately equal to the desired shoreline advancement chosen in step c, X_s , then proceed to step i, and let $X_s = X_s'$, $X = X'$, and $d = d'$, where d is the actual design water depth at the structure. Otherwise, repeat steps e through h until X_s' is approximately equal to the desired value, X_s . By comparing Equations 2 and 4, it is apparent that L_c , the length of the salient in the longshore direction, is assumed for the initial calculation to be twice the structure length L_s .

i. Calculate ranges of structure length L_s using Figures 4 and 5, based on ratios of structure length over local wavelength at the structure L_5 , where $L_5 = T_5(gd')^{1/2}$. Inspection of Figures 4 and 5 results in the following recommended ranges of L_s/L_5 for a sand-type beach:

Beach Type B:

$$1.8 < \frac{L_s}{L_5} < 3.0 \qquad \text{or} \quad 1.8\, L_5 < L_s < 3.0\, L_5 \tag{5}$$

Beach Type C:

$$1.4 < \frac{L_s}{L_5} < 2.3 \qquad \text{or} \quad 1.4\, L_5 < L_5 < 2.3\, L_5 \tag{6}$$

j. Calculate ranges of structure length L_s based on ratios of structure length-to-distance offshore from original shoreline X using Figures 4 and 5. Inspection of Figures 4 and 5 results in the following recommended ranges of L_s/X for a sand-type beach:

Beach Type B:

$$0.8 < \frac{L_s}{X} < 2.5 \qquad \text{or} \quad 0.8\, X < L_s < 2.5\, X \tag{7}$$

Beach Type C:

$$1.0 < \frac{L_s}{X} < 3.5 \qquad \text{or} \quad 1.0\, X < L_s < 3.5\, X \tag{8}$$

k. Using Equations 5 and 7 for a Beach Type B, or Equations 6 and 8 for a Beach Type C, obtain ranges for structure length using the maximum lower value and minimum upper value, i.e., the intersection of the two equations. Structure length is then calculated as the average of the minimum and maximum values.

l. If two times the structure length ($2L_s = L_c$) is less than the length of shoreline to be protected L_p , calculate a gap width L_g

from Figure 6. Inspection of Figure 6 results in the following recommended ranges of gap width for sand-type beaches so that a typical shoreline change at the gap X_g is obtained:

Beach Types B and C:

$$0.7 < \frac{L_g}{X} < 1.8 \quad \text{or} \quad 0.7\, X < L_g < 1.8\, X \tag{9}$$

$$0.5 < \frac{L_g}{L_s} < 1.0 \quad \text{or} \quad 0.5\, L_s < L_g < 1.0\, L_s \tag{10}$$

m. Obtain a range of values for L_g using the intersection of Equations 9 and 10 similar to step k. The gap width L_g can then be calculated as the average of the maximum and minimum values.

n. Develop a functional design using the structure length L_s, gap width L_g, and distance offshore from the original shoreline X such that the length of project shoreline L_p will be protected.

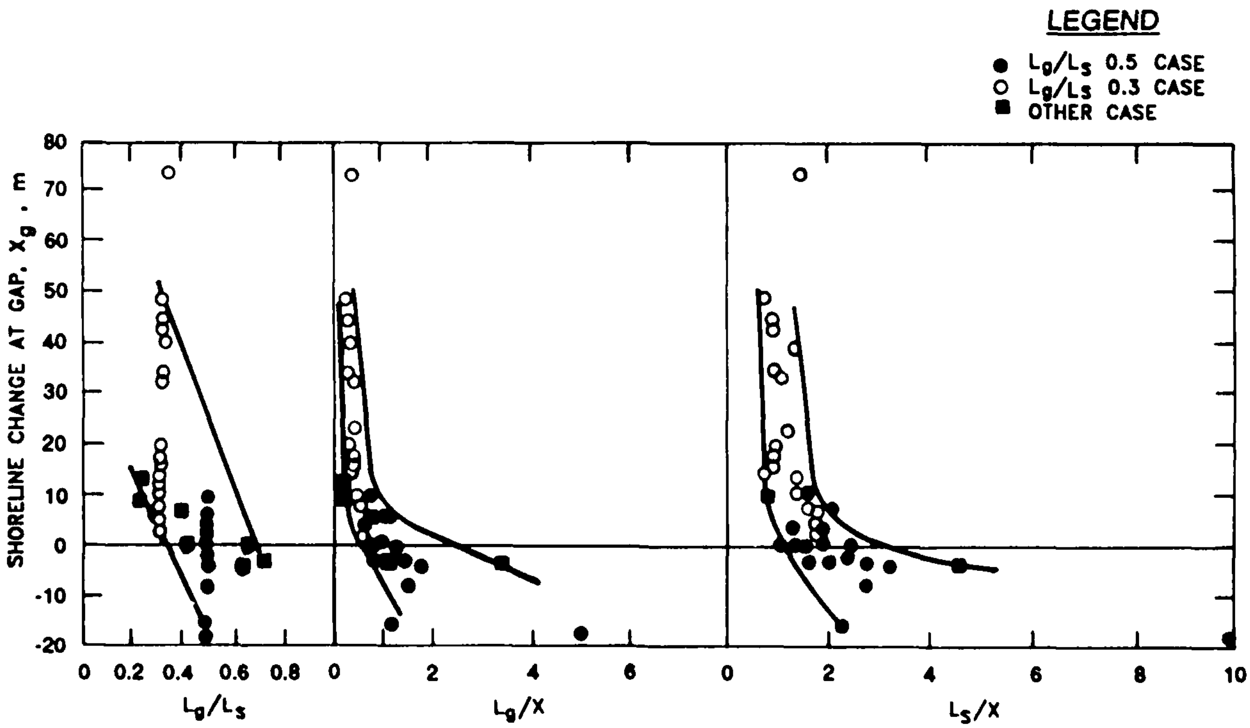


Figure 6. Relationship between nondimensional parameters and shoreline change at gap (JMC 1986)

Example

10. The following example problem illustrates detached breakwater design using the JMC method. Given the average of five highest deepwater wave heights occurring in a year $H_{o5} = 2.5$ m, corresponding wave period $T_5 = 12.0$ sec, desired salient length $X_s = 15$ m, length of project shoreline $L_p = 380$ m, beach slope $I = 1/30$. The beach has a well-developed offshore bar, with sand-sized material.

a. Because the beach is mildly sloped with well-developed bar and sand-sized beach material, classify it as a Beach Type B.

b. Wave parameters and length of shoreline are given.

c. Desired salient length is given.

d. Calculate the deepwater wavelength L_{o5} and deepwater steepness H_{o5}/L_{o5}:

$$L_{o5} = \frac{g\,T_5^2}{2\pi} = \frac{(9.81)(12)^2}{2(3.14)} = 224.8\ m$$

$$\frac{H_{o5}}{L_{o5}} = \frac{2.5}{224.8} = 0.011$$

Using Figure 3 with $I = 1/30$ and $H_{o5}/L_{o5} = 0.011$, estimate

$$\frac{d_{b5}}{H_{o5}} = 1.8$$

Therefore

$$d_{b5} = 1.8(2.5) = 4.5\ m$$

e. Make initial guess of design water depth at structure, d':

$$d' = \frac{d_{b5} + X_s I}{2} = \frac{4.5 + 15\left(\frac{1}{30}\right)}{2}$$
$$= 2.5\ m$$

f. Use Figure 4 to estimate SAR :

$$\frac{d'}{d_{b5}} = \frac{2.5}{4.5} = 0.56$$

From Figure 4

$$SAR = 0.6$$

g. Calculate the first approximation to structure distance offshore X'

$$X' = \frac{d'}{I} = \frac{2.5}{\left(\frac{1}{30}\right)} = 75\ m$$

h. Calculate the first approximation to salient length X_s :

$$X_s' = SAR\ X' = 0.6(75) = 45\ m$$

Since the first approximation to salient length ($X_s' = 45$ m) was not equal to the desired salient length ($X_s = 15$ m), repeat steps e through h with a second estimate of structure depth, d' . Let water depth at structure $d' = 1.5$ m ; then, using $d'/d_{b5} = 0.33$, estimate $SAR = 0.35$. The structure distance offshore is then $X' = 1.5/(1/30) = 45$ m , and the estimated salient length $X_s' = 0.35(45) = 15.8$ m , approximately equal to desired salient length (15 m). Therefore, $X_s = X_s' = 15.8$ m , $X = X' = 45$ m , and $d = d' = 1.5$ m .

i. Calculate the local wavelength at the structure:

$$L_5 = T_5 \sqrt{gd} = 12.0 \sqrt{9.81\ (1.5)} = 46.0\ m$$

Calculate the ranges of structure length using Equation 5:

$$1.8\ L_5 < L_s < 3.0\ L_5$$
$$1.8\ (46.0) < L_s < 3.0\ (46.0)$$
$$82.8\ m < L_s < 138.0\ m$$

j. From Equation 7, ranges for structure length are

$$0.8\ X < L_s < 3.0\ X$$
$$0.8\ (45.0) < L_s < 2.5\ (45.0)$$
$$36.0\ m < L_s < 112.5\ m$$

k. Obtain ranges for structure length, L_s, using the intersection of Equations 5 and 7:

$$82.8\ m < L_s < 112.5\ m$$

Structure length is calculated as the average of the extremes:

$$L_s = \frac{82.8 + 112.5}{2} = 98\ m$$

l. Calculate the gap width:

From Equation 9:

$$0.7\ X < L_g < 1.8\ X$$
$$0.7\ (45) < L_g < 1.8\ (45)$$
$$31.5\ m < L_g < 81.0\ m$$

From Equation 10:

$$0.5\ L_5 < L_g < 1.0\ L_5$$
$$0.5\ (46.0) < L_g < 1.0\ (46.0)$$
$$23.0\ m < L_g < 46.0\ m$$

m. Obtain ranges for gap width using the intersection of Equations 9 and 10:

$$31.5\ m < L_g < 46.0\ m$$

The gap width is calculated as the average of the two values:

$$L_g = \frac{31.5 + 46.0}{2} = 39\ m$$

n. To protect the length of the project shoreline L_p = 380 m three breakwater segments with length L_s = 98 m are required, with a corresponding gap width L_g = 39 m (Figure 7).

11. Three additional example breakwater designs have been completed for this report but are not presented in their entirety. Example problems 2 and 3 modify input parameters slightly from example problem 1, presented above, to observe the effect of these parameters on the design. Example problem 4 is a design of the Lakeview Park project (USACE 1984; Walker, Clark, and Pope 1980)

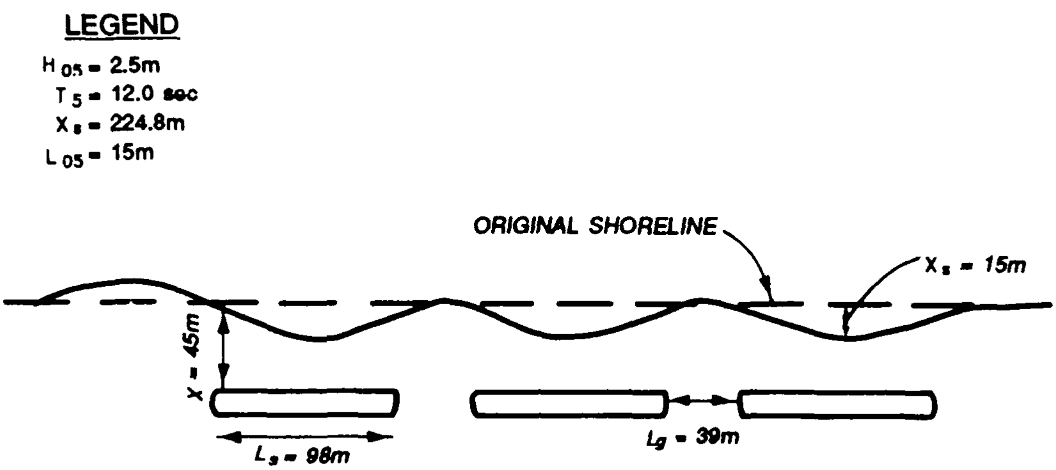


Figure 7. Design example 1

using the JMC method, so that a typical US design can be compared with the JMC design.

12. Example design problem 2 uses the same input parameters as used in design problem 1, except the desired salient length X_s is doubled to 30 m . The resulting design for problem 2 is presented in Figure 8. The JMC design positioned the structures slightly farther offshore in problem 2 and lengthened both the structure length and gap width to obtain a greater salient length. Movement of the structures offshore in itself would tend to decrease the effect of the structures on the shoreline; however, lengthening of the structure from 98 to 123 m probably would increase the influence of the structure on coastal processes and allow the larger salient to deposit in problem 2.

13. Design problem 3 used the same desired salient length X_s and other input parameters as specified in problem 2, but wave conditions were milder with a deepwater wave height (average of five highest waves in a year) $H_{05} = 1$ m and corresponding wave period $T_5 = 6$ sec. The resulting design decreased the structure length more than half and moved the structures closer to the original shoreline (Figure 9).

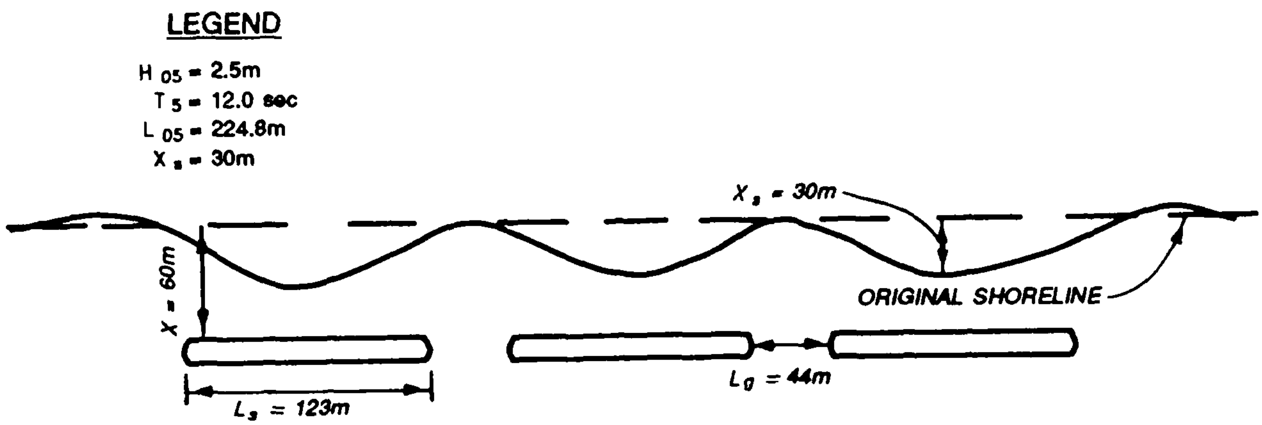


Figure 8. Design example 2

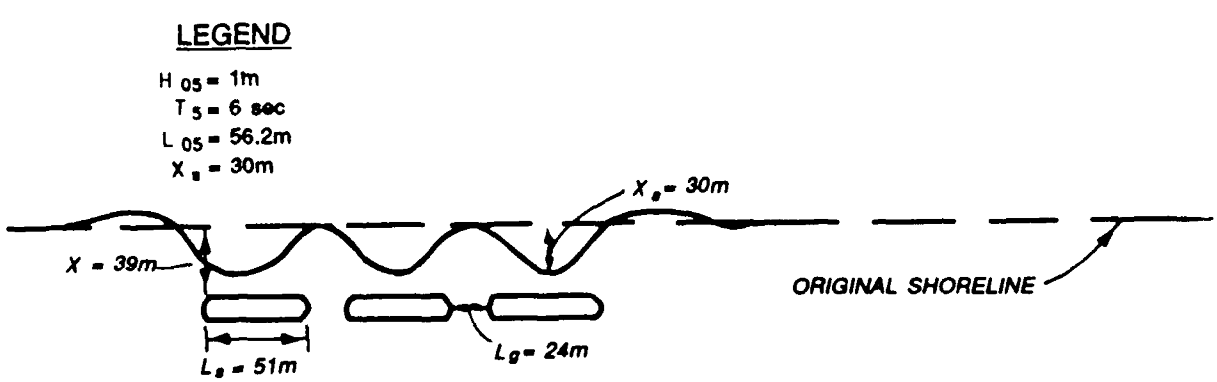


Figure 9. Design example 3

14. The JMC design method was applied to the Lakeview Park project, using a bidirectional wave climate idealized to occur equally from the north (H_{o5} = 1.7 m , T_5 = 4.4 sec) and northwest (H_{o5} = 2.3 m , T_5 = 4.7 sec) (USAED, Buffalo 1975). The desired salient length X_s was chosen to be equal to the average salient length $\bar{X}_s$ observed from prototype response ($X_s = \bar{X}_s$ = 26 m); project length was L_p = 390 m , and beach slope I = 1/25 (Beach Type B). Project parameters were calculated for the north and northwest wave conditions and then averaged to obtain a project design. The JMC design resulted in six segments approximately 40 m in length, placed approximately 39 m offshore with a gap distance of 23 m (Figure 10). Comparing the JMC design with the existing Lakeview Park project parameters (Figure 11), twice as many segments are indicated, with segment length decreased 35 percent. Both the gap width and distance offshore are decreased by half in the JMC design.

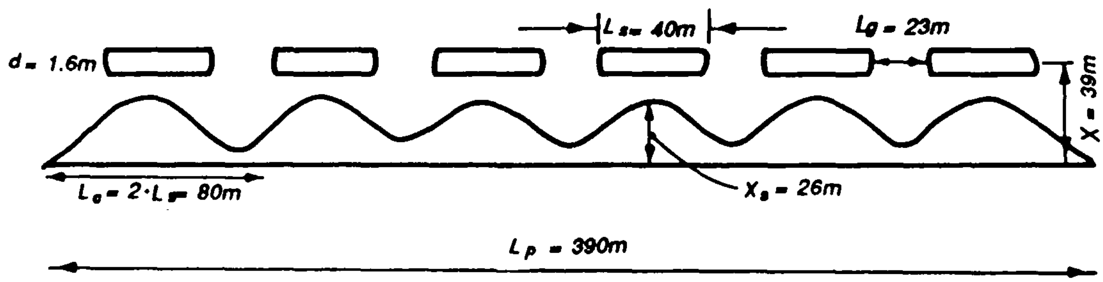


Figure 10. Design example 4

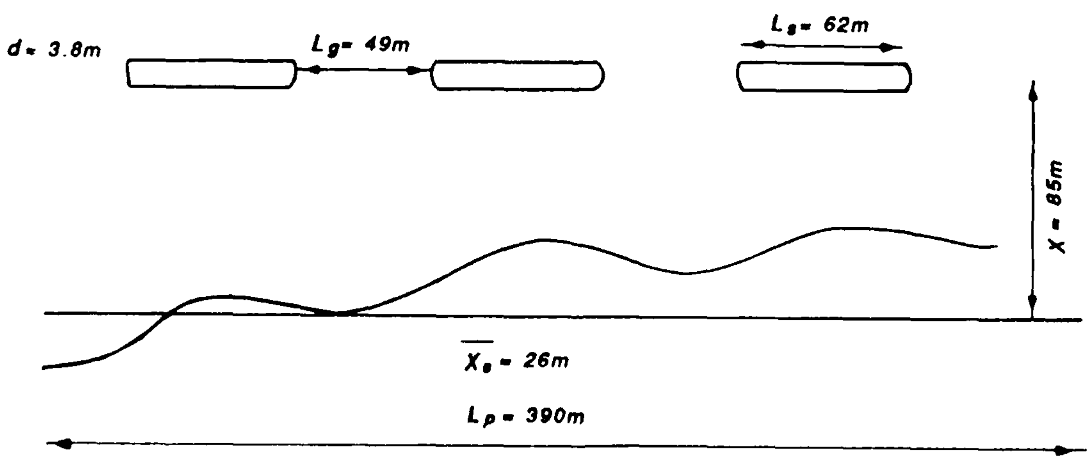


Figure 11. Lakeview Park actual shoreline response

Conclusions

15. Design of detached breakwater systems using the JMC method described tends to result in more numerous, shorter length segments with a decreased gap width. The structures are typically designed closer to the original shoreline than observed in US projects. Empirical relationships developed from US data presented in the SPM (1984) and Dally and Pope (1986) predict that the shoreline will connect to the structure (true tombolo formation) at each of the four design problems presented previously.

16. A problem which has plagued detached breakwater design is that there are so many interrelated parameters to be considered (wave climate, structure length, distance offshore, gap distance, beach sediment characteristics, nearshore bathymetry, etc.) that the designer is often at a loss as how to start the process. Certainly this problem can (and has) been successfully treated by using an iterative approach. The JMC design procedure has been illustrated to give reasonable project parameters for four example problems and may provide an alternative design process for field use. As with any design procedure, the limitations of the JMC method (i.e., provisions for tide or water-level change not explicitly incorporated, procedure developed with beach response data to transmissible armor unit structures, simplified wave climate used as input, etc.) must be realized throughout the design process. However, the JMC procedure may serve to identify the specific steps and knowledge required in the design, suggesting directions for future research and better monitoring.

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Appendix A: Notation

d	Design water depth at structure
d'	Approximation to d
d_{b5}	Breaking water depth at site based on H_{o5} and T_5
g	Acceleration of gravity (9.81 m/sec^2)
H_{o5}	Deepwater wave height calculated by averaging the five largest nonstorm waves that occur in a year (m)
I	Beach slope
L_5	Wavelength at structure corresponding to deepwater conditions H_{o5} and T_5
L_c	Alongshore salient width, measured at original shoreline
L_g	Gap distance between adjacent breakwater segments
L_{o5}	Deepwater wavelength corresponding to T_5
L_p	Alongshore project length (length of shoreline to be protected)
L_s	Breakwater segment length
SAR	Salient area ratio
T_5	Wave period corresponding to H_{o5}
X	Breakwater segment distance from original shoreline
X'	Approximation to X
X_g	Shoreline change at gap
X_s	Desired shoreline advancement, salient length
X_s'	Approximation to X_s
$\bar{X}_s$	Average salient length for project